RIVER MORPHOLOGY, FLOOD EROSION AND PROTECTVE WORKS FOR FARAKKA BARAGE ON RIVER GANGA

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Abstract

Thorough knowledge of river morphology and river meandering process, as outlined in this paper, are essential for proper planning and design of river works related to Ganga rejuvenation project. Flood erosion and protection works experienced in case of Farakka barrage have been discussed in detail with a view to take care of similar problems in future.

KeyWords: Morphology, Meandering, erosion, Farakka, protection

1.INTRODUCTION

Ganga basin (Fig.1) has a catchment area of 8,61,452 sq.km in India out of the total catchment area of 10, 86,000 sq. km. lying in China, Nepal, India and Bangladesh. Mean annual flow in the river is about 14,000 cumec and it carries sediments of about 800 million tons/year at Farakka barrage (Sanyal, 1980). Maximum observed flood discharge at Farakka as on 6.9.98 was 75,900 cumec and corresponding HFL was 26.545m. Seasonal and yearly distribution of flow are extremely non-uniform (Fig.2) due to highly non-uniform rainfall in monsoon lasting for about 2-3 months in a year.

Primary objective of Ganga rejuvenation is to make the river clean and free from pollution. This can be achieved by treatment of effluents from domestic, agricultural and industrial sectors. Another way of pollution control is through the process of dilution of the waste water by ensuring enough river flow all the time so that the concentration of pollutants is within safe limit. Ganga rejuvenation is necessary also to make the river navigable which is an economic mode of transport compared to roads and railways.

To meet the above objectives as well as the requirements for irrigation, hydro-power, flood control, domestic, & industrial uses , protection of aquatic life, navigation, recreation etc., flood water of Ganga must be conserved in upstream storage reservoirs in order to ensure guaranteed supply throughout the year. As per the assessment done by CWC in the year 1993, the average annual water availability in the country is 1869 billion cubic meters (BCM) out of which Ganga basin has a potential of 525 BCM with an utilizable surface water resources of 250 BCM (Iyer,1989). Table-1 gives the water requirement for various uses in the country. Thorough knowledge of river morphology, river erosion and protection works is needed for proper

planning, designing, construction, operation and maintenance of all river works associated with Ganga rejuvenation. Author wishes to discuss in this paper some of the problems faced due to construction of Farakka barrage on Ganga so that the engineers engaged in the rejuvenation works can foresee and preplan to avoid similar problems in future.

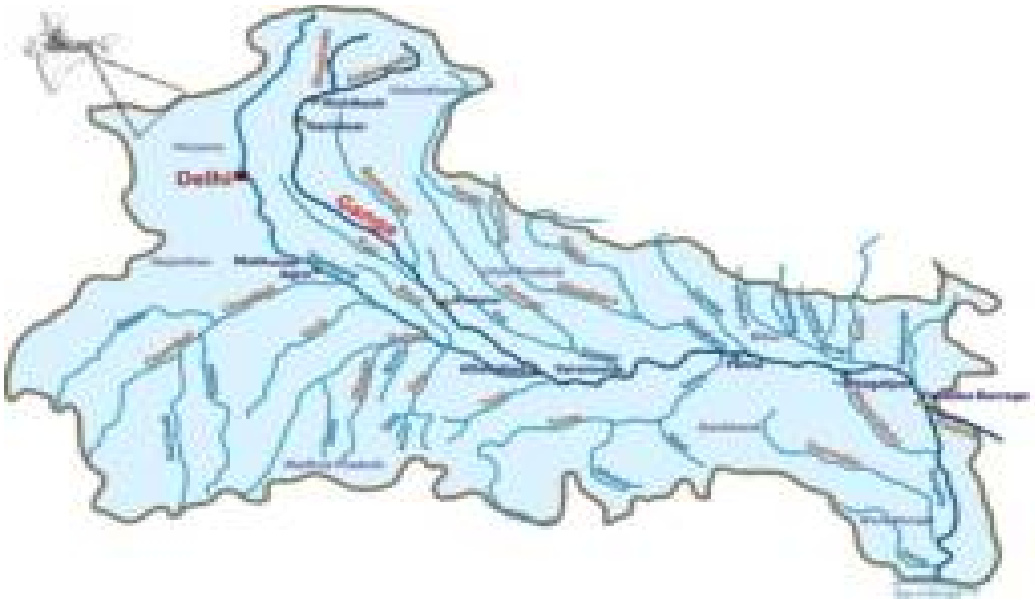

Fig.1 Showing River Ganga and its Tributaries.

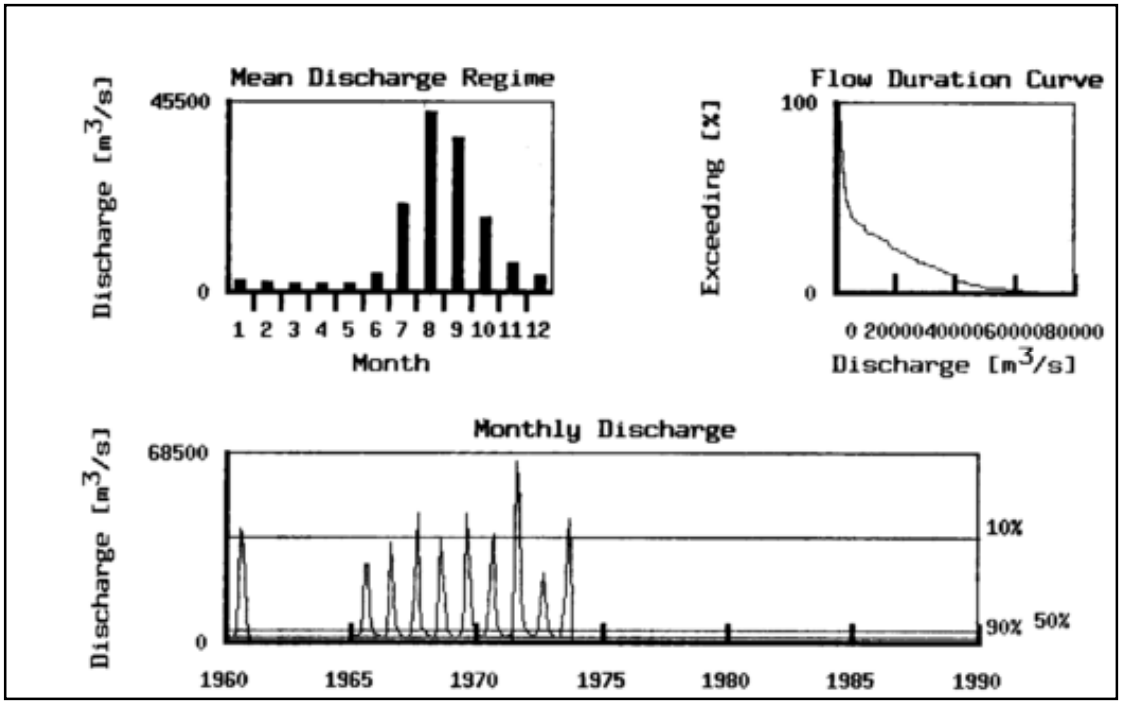

Fig.2. Some Typical Distribution of Mean Monthly Flow and Foods in Ganga at Farakka

Table-1 Total water requirement of the India for different uses (NCIWRD-1999)

Sl.No.	Total Water Requirement for Different Uses (in BCM)			
	Uses	Year 2010	Year 2025	Year 2050
		High Demand scenario	High Demand scenario	High Demand scenario
1.	Irrigation	557	611	807
2.	Domestic	43	62	111
3.	Industries	37	67	81
4.	Power (Energy)	19	33	70
5.	Others	54	70	111
	Total	**710**	**843**	**1180**

2. RIVER BEHAVIOR AND EROSION OF BANKS NEAR FARAKKA BARRAGE

Farakka barrage-about 2.6 km long- was constructed in the year 1967 across river Ganga with the objective of forcibly diverting flow from the parent river Ganga to its tributary, Bhagirathi/Hoogly which was drying up due to silting of it's off take point at a place called Jangipur (at a distance of about 40 km downstream of the barrage), resulting in gradual reduction of fresh upland flow from Ganga. Bagirathi/Hoogly river flows through West Bengal for a length of about 500 km from its off take to its outfall in Bay of Bengal. It is the lifeline of west Bengal as it is the principal source of water for municipal and industrial uses for Kolkata and Howrah cities and many other important towns located on either bank of Bhagirathi/ Hoogly which is a navigable tidal river. Kolkata port located on river Hoogly was drying up due to siltation, as the fresh water upland discharge was reducing. Under the recommendation of CW&PRS (Pune) and advise of experts from India and abroad, Ministry of Water Resources, Govt. of India, decided to construct Farakka barrage on Ganga and Jangipur barrage on Bhagirathi for diverting 1135 cumec continuous flow to Hoogly river through a Feeder canal which is about 34 km long. The cost of the project at 1973 price index was nearly Rs.2, 000 million.

During the pre-barrage period, the main course of Ganga between Rajmahal and Farakka was along the right bank and the stretch was almost straight (Fig.3a). After the barrage was constructed, the main course of the river upstream of barrage shifted towards the left bank and that on the downstream side it shifted towards right bank..With continued erosion of its left bank upstream and right bank downstream of the barrage, Ganga has developed a typical meander with left bank on the outer side of upstream bend and the right bank on the outer side of downstream bend. There is a severe embayment of the river Ganga upstream of the barrage and it may cause outflanking of the barrage if the erosion upstream is not arrested. This unprecedented rate of meander migration is about 10 times more than that predicted by Hickin and Nanson (1984) as illustrated in Fig.3(b), perhaps due to the interaction between the river Ganga and the barrage. On the downstream side also, the right bank of the river has similar

erosion problem. Several towns have been completely wiped out and in certain stretches the distance between the railway line and bank has been reduced to 200 m or so compared to an earlier distance of 5 km in pre barrage stage.

Continued erosion of the river upstream and downstream of the barrage has resulted in colossal loss of agricultural and household properties and subjected the people living near the banks to unimaginable sufferings. Properties worth several thousand million rupees have been lost or damaged both upstream and downstream of the barrage If the erosion and embayment on the left bank continues upstream, there is a possibility of change of the present course of Ganga wiping out thickly populated areas in the Malda district of West Bengal (Mazumder,2000). The marginal bund has already been severely damaged. The afflux bund, the railway line and the national highway NH-34 connecting north-east India with the rest of the country, have also breached several times resulting in loss of both agricultural and household properties and subjecting the people living in Malda district(u/s) and Murshidabad district(d/s) in West Bengal to unprecedented miseries. If the river course changes upstream, the barrage and the feeder canal will be useless and the Bhagirathi river will again go dry. On the other hand, if the erosion of right bank continues downstream, the railway, the roadway, the feeder canal and the Jangipur Barrage are likely to be washed out. The river may either join parent Ganga or may merge with Bhagirathi/Hoogly river. In either case, there will be further loss of life and properties and the purpose of the barrage and the feeder canal will be lost.

Considering the gravity of the situation and complexity of the problem , it is necessary that an in depth analysis of the erosion problem should be made with all relevant field data, especially regarding incoming and outgoing sediment load and sediment deposition upstream. The river course, the meandering and the erosion of the banks are interrelated and governed by both flow of water and sediments. One of the objectives of writing the paper is to make the river engineers aware of the morphological and meandering processes involved in the unprecedented erosion of Ganga banks compelling the Govt. to adopt costly protective measures both upstream and downstream of Farakka barrage.

3.RIVER MORPHOLOGY

3.1 River planform and Bed Form

Understanding the behavior of any given river is complicated due to interrelated geomorphologic, hydraulic and hydrologic parameters (Mazumder,2004). The interrelation between plan form, hydraulic and sediment parameters and relative stability of a river is illustrated in Fig.3 (a) & 3(b) (Schum, 1981). It may be seen that the different plan forms of a river e.g. straight, meandering and braided course depend on the geometry, sediment load, slope of bed and discharge of the river. Interrelation between stream form, bed slope and mean discharge is illustrated in Fig. 3(a) (Lane 1957). A decrease in discharge combined with increase in sediment load will result in decrease in flow depth and increase in flow width as mostly

observed upstream of hydraulic structures e.g. barrages and bridges Prediction of stream response to climatological and watershed changes is based on the fundamental relation given by equation- 1 (Lane ,1955, Garde,2006).

$$QS_e \ \alpha \ Q_s d_{50} \ldots. \qquad \ldots\ldots\ldots(1)$$

where, Q is the discharge, S_e is energy slope, Q_s is sediment transport rate and d_{50} is median size. of sediment. When flood plain of a river is restricted either vertically or laterally or both simultaneously, there is afflux and back water upstream resulting in reduction in energy slope (S_e). Q and d_{50} remaining same, the stream power (Q.Se) and the sediment carrying capacity of the river (Qs) are reduced. As a result, there is deposition of sediments resulting in aggradations upstream. Unfortunately, the deposition is never uniform in a river flowing in meandering regime observed in case of Ganga near Farakka barrage. In all diversion structures (like Farakka barrage), comparatively clear water is withdrawn from upstream resulting in decrease in Q downstream. As a result, stream power (Q. S_e) gets reduced and hence the sediment carrying capacity (Q_s) is reduced, d_{50} remaining the same. Obviously, sediments will be deposited downstream of such diversion points and there will be aggradations. Heavy silting has occurred on the left bank side of Ganga in the vicinity of Farakka barrage pushing the river towards right bank side downstream.

3.2 RIVER STABILITY AND MEANDERING PROCESSES

Interrelation between stream form and bed slope is schematically illustrated in Fig. 3(a) and3(b).Quantitative relationships (Eq.2&3) between channel bed slope (S_o) and mean flows (Q) are presented by Lane (1957). A non cohesive stream bed composed of silts and sands is predicted to meander when

$$S_o \, Q^{0.25} > 0.00070 \ldots\ldots\ldots \qquad (2)$$

and braided when

$$S_o \, Q^{0.25} > 0.0041 \ldots\ldots\ldots\ldots \qquad (3)$$

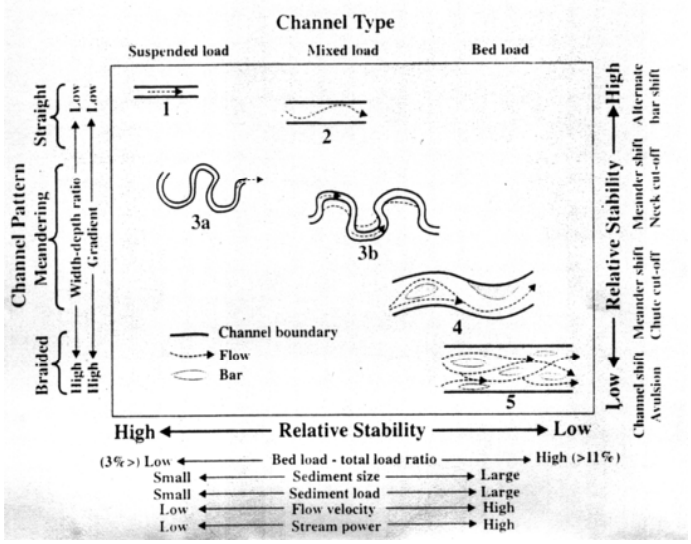

Fig.3(a)Interrelation betweeeen channel type, hydraulic and sediment parameters (Schum, 1981)

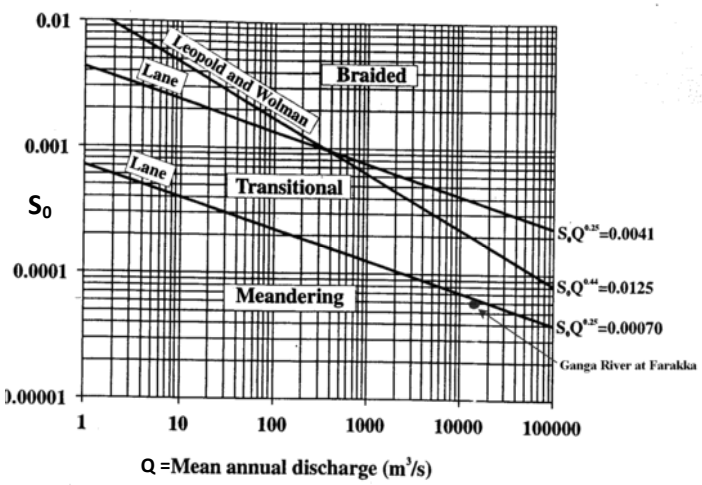

Fig. 3(b) Interrelation between stream forms , bed Slope and mean discharge (Lane, 1955)

A typical straight stream is rarely stable. As shown in Fig. 3 (a), streams with very small width to depth ratio) may be stable for some distances. Development of lateral instability associated with erosion and deposition give rise to meandering processes as illustrated in fig. 4 (a). A lot of research work on bends in a meandering river have been carried out by eminent river scientists like Rozovsky (1957), Zimmerman and Kennedy (1978), Engueland (1973), Oddgard (1986), Wang (1994), Yalin (1999), Chitale (1981), Garde and Raju (2000). Centrifugal effect of flow curvature in a river bend results in the development of secondary current which when superimposed with axial flow causes spiral motion in a bend. Wang (1992) developed a mathematical model of the meandering processes to prove that the typical cross-slope as observed u/s and d/s in a meander with lower bed elevation on the outer side of the bend (due to erosion of outer bank) and higher elevation of bed on the inner bank side (due to deposition of the eroded materials on the inner bank) provides stability to the stream. Hickin and Nanson (1984) described the lateral migration rate (M) of a meandering stream by the functional relation:

$$M = f(\Omega, b, G, h, \tau_b) \quad \ldots. \quad (4)$$

Where Ω is stream power (τ.v), b is a parameter expressing plan form geometry of the stream, h is the height of outer bank (degree of incision), τ_b is the erosional resistance offered by the outer concave bank undergoing erosion. Plotting measured migration rate (m/year) against relative curvature (r/w, where r is the radius of curvature and w is the stream width), as shown in fig. 4(b), Hickin and Nanson concluded that the migration rate is maximum when meander stabilizes at an approximate value of r/w =2.5 and got the relation (Eq.5)

$$M_{2.5}\ (m/year) = \rho g\, QS / \tau_b h \quad \ldots\ldots\ldots(5)$$

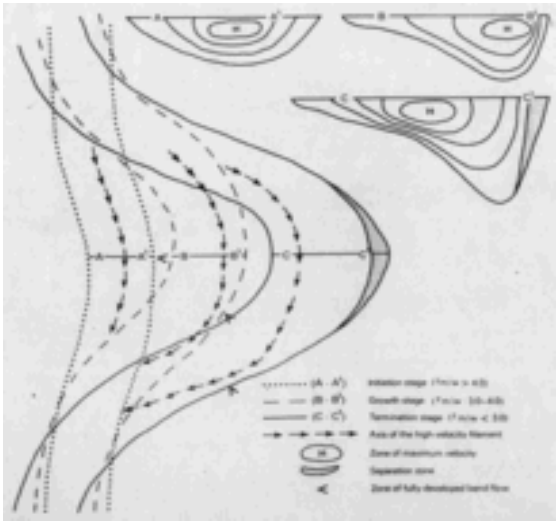

Fig.4(a) Lateral Migration of meander and development of Stream Section in a Bend

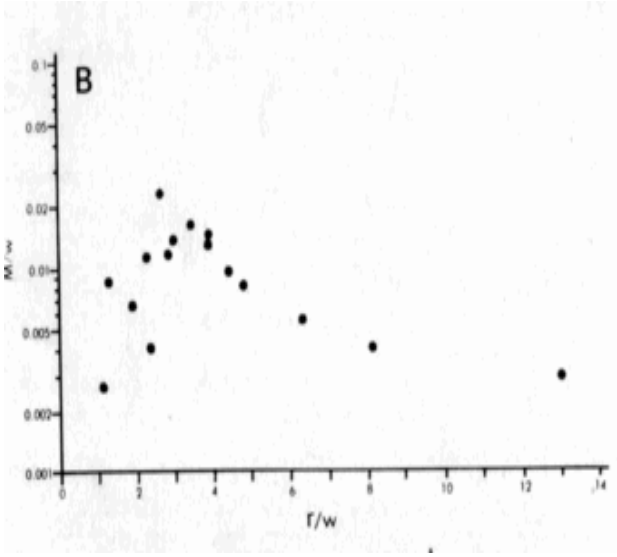

Fig4(b)Variation of Migration Rate,M (m/yr) with Relative Curvature (r/w) in a Meander

Where, $M_{2.5}$ is the maximum rate of migration corresponding to r/w = 2.5. Migration of meander, as illustrated in fig.4(a) occurs on the outer bank side subjected to higher stream flow concentration and consequent erosion of outer bank. Uncontrolled meandering may lead to outflanking of hydraulic structures and flow avulsion when the river shifts its course and it may join other low lying rivers - tendencies as observed in the case of Farakka barrage. Uncontrolled erosion on the outer bank side and deposition on the inner bank side lead to formation of meander (Fig.4a), especially where the banks are made of fine alluvial soil of extremely poor shear strength (τ_b) as in Farakka (d_{50} of bed material is about 0.15mm). Also, the critical shear stress at which the materials start moving in outer bank of meander is much less compared to that in a straight reach (Mazumder,2010).

4. USE OF IMPERMEABLE SPURS TO CONTAIN EROSION AT FARAKKA BARRAGE

Farakka barrage is designed for a flood discharge of 70,930 cumec (25 lakh cusec) with a design afflux of 0.5 m. Further details of the barrage are available elsewhere (Mazumer,2001&2004). With a longitudinal bed slope of 1 in 21,000 and a mean annual flow of about 14,000 cumec, the river is in a meandering state as indicated in Fig. 3 (b). It is estimated that approximately 1.3 Mha-m of sediments have already been deposited upstream of the barrage causing formation of several shoals/bed bars, meandering, cross-slope, strong flow curvature and lateral flow instability upstream of the barrage. With the continued erosion of its left bank upstream and right bank downstream of the barrage, a typical meander has developed with Malda on the outer side of the upstream bend (left bank) and Murshidabad on the outer side of the downstream bend (right bank) with Farakka Barrage (a rigid structure) at the centre acting as a nodal /fixed point (Fig.5a and Fig.5b). The river has extensively eroded its left bank and developed a sharp curvature. Figs.6(a) shows a typical sketch of river cross-section in the meandering zone upstream of the barrage, indicating deep scour(50m below HFL as on 31.10.2000) near the left bank. In 1972, a 30 km long marginal embankment was constructed along the left bank upstream of the barrage to stop erosion and further migration of the river towards the left bank. Subsequently, 27 numbers earthen core type impermeable spurs (duly protected with heavy stones in GI wire nets for preventing erosion), were constructed for protecting the marginal embankment with a view to train the river up to the barrage. But the embankment was breached on several occasion during high floods and most of the spurs have been washed out. The river has moved about 7 km inside Malda district (Fig.5a) wiping out thickly populated villages near the left marginal embankment. 450 people died and properties worth about rupees 10,000 million were damaged in 1998 flood alone (Mazumder 2000). Near Panchanandpur, where the river has taken the sharpest bend and breached the marginal embankment on several occasion, retired embankments with stone pitching and submerged stone spurs were constructed eight times around the breaches in order to protect the people and the properties from flood damage. However, all these retired embankments and majority of the spurs and the protective works have been swallowed by the mighty Ganga year after

year. The protection measures adopted for the ninth retired embankment consist of similar stone pitching in GI wire net(laid over graded filter) up to a length of 50 meter starting from RL +25m and ending at a point in the river bed where the river bed level is +3 meter in lean flow season. 50m width launching apron made of crated stones was laid over Tarja . Submerged spurs made of stones in GI wire net and 3-meter high above the river bed were also constructed over the apron at a spacing of 100m centre to center. Yet the erosion of left bank could not be controlled with a possibility of avulsion of the mighty river Ganga bypassing the barrage. If it happens, river Ganga will change its course and it is likely to join the low lying rivers like Pagla, Kalindri and Mahananda on its left bank as shown in Fig,5(b). In that case, the

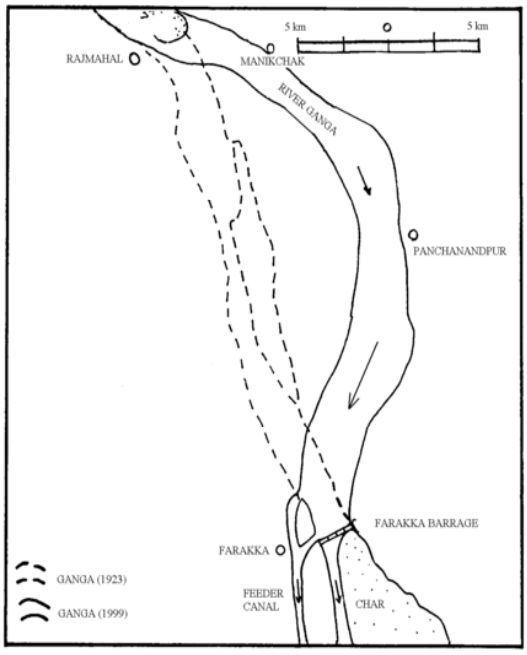

Fig.5(a)Shifting Ganga towards Malda u/s of Farakka Barrage

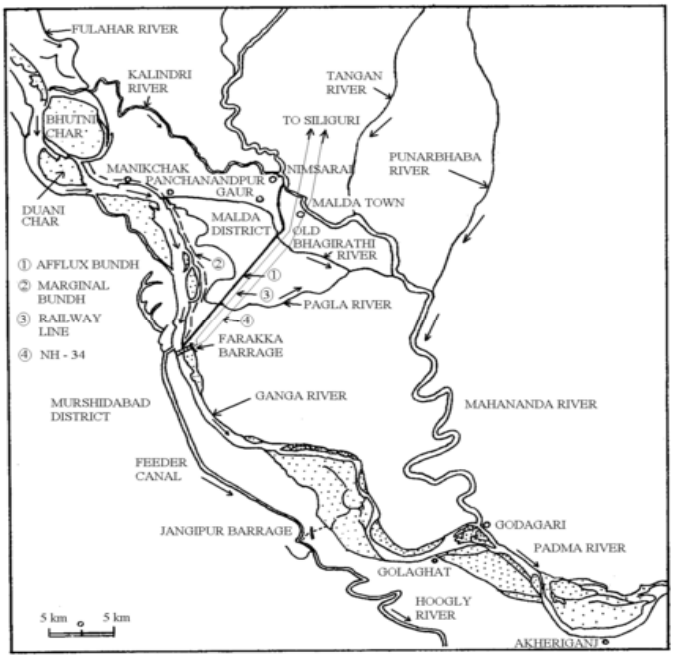

Fig.5(b)Meandering Ganga Course and tributaries u/s and d/s of Farakka Barrage, Feeder Canal etc.

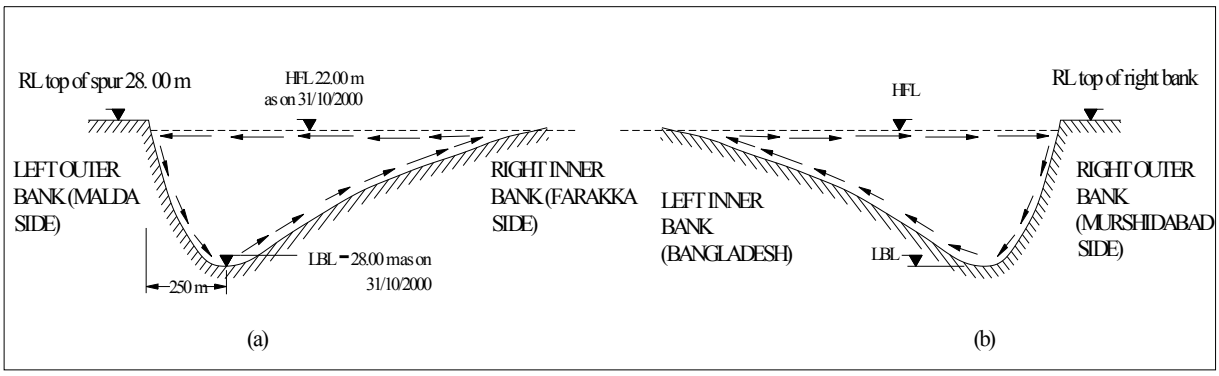

Fig.6 Showing Typical Cross Sections of Ganga River (a) Upsream (b) Downstreamn of Farakka

barrage will be ineffective and it will cause colossal damage to Malda district including the National highway (NH-34), railway line and afflux bund protecting Malda town.

Downstream of Farakka barrage, the river Ganga has extensively eroded its right bank in Murshidabad district of West Bengal. The downstream meander has already migrated about 4 km on the right bank side resulting in development of deep scour and cross-slope near the right bank as illustrated schematically in Fig.6(b). Extensive erosion of right bank has resulted in loss of valuable agricultural lands and household properties, damage to roads and communication system subjecting the people to extreme miseries. It is threatening the existence of several townships located on the right bank of the river Ganga. About 26 km length of river bank was protected with stone pitching and 87 nos. of submerged stone spurs were built on the right bank of the river to control river erosion. 26 spurs and 15 km of pitching have been washed out and a number of spurs and the stone pitching have been badly damaged. If the erosion continues further, the river may merge with the Feeder canal defeating the very purpose of the barrage. Railway line, NH-34 and Jangipur barrage will be washed out.

A master plan of riverbank protection, both upstream and downstream of the barrage, has been drawn to control erosion of river banks and prevent further migration of the river meander at a cost of about Rs 9270 million as per the recommendations of Pritam Singh Committee (1980) and Keskar Committee (1996). Unfortunately, the recommended conventional protective works, consisting of impermeable earth-core type spurs protected with stone pitching and submerged stone bed spurs over stone mattress (in GI wire net), have miserably failed to perform. Most of the impervious spurs are already destroyed due to heavy erosion at their heads and toes. The river banks made of very fine non-cohesive alluvial soil are subjected to the fury of the river causing erosion of the bank. The sand and silt layers underneath the bank get eroded first and the top clayey bank caves in the scoured area due to lack of any support from bottom.

The spurs which are designed as deflecting type originally are now behaving as attracting type due to scouring of the banks upstream of the spurs and consequent river embayment upstream of the spurs. Longer the spur, higher is the flow concentration at heads and more vulnerable is the spur heads to failure. Both Pritam Sngh and Keshkar committee had recommended use of still longer solid spurs for deflecting the current causing higher flow concentration at spur head It is almost impossible to retain them in position when the measured depth of scour is as high as 50m below HFL (Fig.5a). This may also cause further complications due to flow instability associated with high degree of contraction and subsequent expansion of flow around the long spurs. An unstable flow can change its course in any direction with slightest disturbance which is inherent in a stream (Mazumder & Pramod Kumar,2001).

The contemporary idea propounded by Lacey(1930) and Inglis(1949) and incorporated in the relevant IRC code (IRC-89:1997) and IS codes (IS: 6966-Pt.I:1989), (IS: 8408 :1994), (IS: 10751 :1994) , (IS: 12094 :2000), (IS:14262:1995), that stones dumped in the horizontal apron will be launched uniformly to protect the scoured area is a myth. Launching never occurs uniformly. The fine bed materials exposed to high velocity current (due to non-uniform launching) are removed/winnowed being entrained /trapped in the current moving over the uneven stone pitched surface resulting in scouring and foundation failure. High velocity current flowing over submerged stone spurs of 3m height causes high stream curvature (in vertical plane) and stronger suction/ winnowing of base materials. Also, these stone spurs soon become impervious due to arrest of sediments moving with the flowing water. As a result, there is high concentration of flow at their heads and development of sharp flow curvature near their heads, causing erosion at heads and progressive failure of the spurs and the stone apron.

Another important reason of failure of spurs and stone pitching is improper choice of filter material. It is doubtful whether tarza mat with innumerable pores at joints will ever act as appropriate filter/separator with so fine soil underneath. Fine base materials may be trapped /winnowed through the innumerable joints in the tarja mat due to dynamic suction when high velocity stream flows over the pitching. Laying the stone apron and submerged bed spurs made up of 1mx1mx1m size crated stones with tarja mat underneath, result in innumerable junctions (and possible gaps) between consecutive units while sinking them from burges under a standing depth of water. Due to lack of control, type of tools used, and the dishonest engineers and contractors engaged in construction., there is further non-uniformity in pitching and exposure of foundation soil to the strong current causing erosion and winnowing of base material resulting in the failure of protection works which are very costly.

5.USE OF PERMEABLE SPURS AND WIRE CRATED STONE OVER GEO-TEXTILE FILTER

After visiting the site and witnessing the severe bank erosion, author suggested the project authorities to use permeable type spurs and stone pitching laid over geo-textile filter after proper soil testing to find the type and mesh size of the textile. It was decided by the project authorities to use porcupine type permeable spurs and the geo-textile filter below crated stone apron. With above arrangements, it is reported that the left bank erosion is controlled. Due to induced siltation near left bank u/s of the barrage, Ganga is reported to be shifting away from the left bank upstream. Further, by judicious gate operation, silts deposited on the left bank d/s of barrage has been flushed out. Thus the flow concentration on both left bank upstream and right bank downstream has been reduced and the severe scour found earlier has been controlled to a large extent.

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